P-28: Effects of Image Generation Variables on Aircraft-Roll Detection Range

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Abstract

We assessed effects of flight-simulator spatial resolution and antialiasing on aircraft-roll detection range. We found that detection range increased with resolution and antialiasing. The antialiasing effect was greater for the lower resolution. These effects held over three levels of aircraft-roll magnitude (task difficulty).

1. Introduction

Many military aviation tasks require accurate perception of the orientation and motion of other aircraft. With current technology, however, flight-simulator imagery does not support performance of such perceptual tasks at realistic ranges.

A typical flight simulator visual system has SXGA (1280 x 1024 pixel) resolution with a field of view (FOV) of approximately 74° x 62° [1], which results in each pixel subtending a visual angle of 3 - 4 arcmin. The human visual system can detect gaps as small as $0.5 - 1.0$ arcmin [2]. Thus, the spatial detail visible in flight simulator images is limited by the simulator and not by the human visual system. In order to approach eye-limited resolution, a pixel should subtend not more than 1 arcmin.

During simulated flight, a section of a virtual world is mathematically projected onto a "view plane" internal to an image generator (IG). This section, or viewing volume, is determined by the viewpoint position, the view direction and angle, the FOV, and the near and far clipping planes. To create a sequence of images as the viewpoint moves through the virtual world, the IG samples the corresponding, time-varying image in both space and time [3]. The horizontal and vertical sampling rates are determined by the pixel mosaic; the temporal sampling (image update) rate is limited by the refresh rate of the display device.

In order to provide perceptually continuous, smooth motion, most IGs attempt to maintain an update rate that equals the refresh rate (e.g., 60 Hz). In order to improve image quality, some IGs implement spatial antialiasing procedures [3].

Figure 1 illustrates the effects of IG resolution and (anti)aliasing on the representation of a black, untextured model of an F-16 surrounded by blue sky. Without antialiasing, the color of a pixel equals the color of the original image at the sampled point. With 4x antialiasing, the color of a pixel equals the average of four subpixel values: black, 0.25(blue), 0.50(blue), 0.75(blue), or blue.

Perceptual tasks that involve detection or discrimination of small differences in object representation are likely to be affected by rendering quality and thus by spatial resolution and antialiasing. In the present study, we assessed the effects of these variables on aircraft-roll detection.
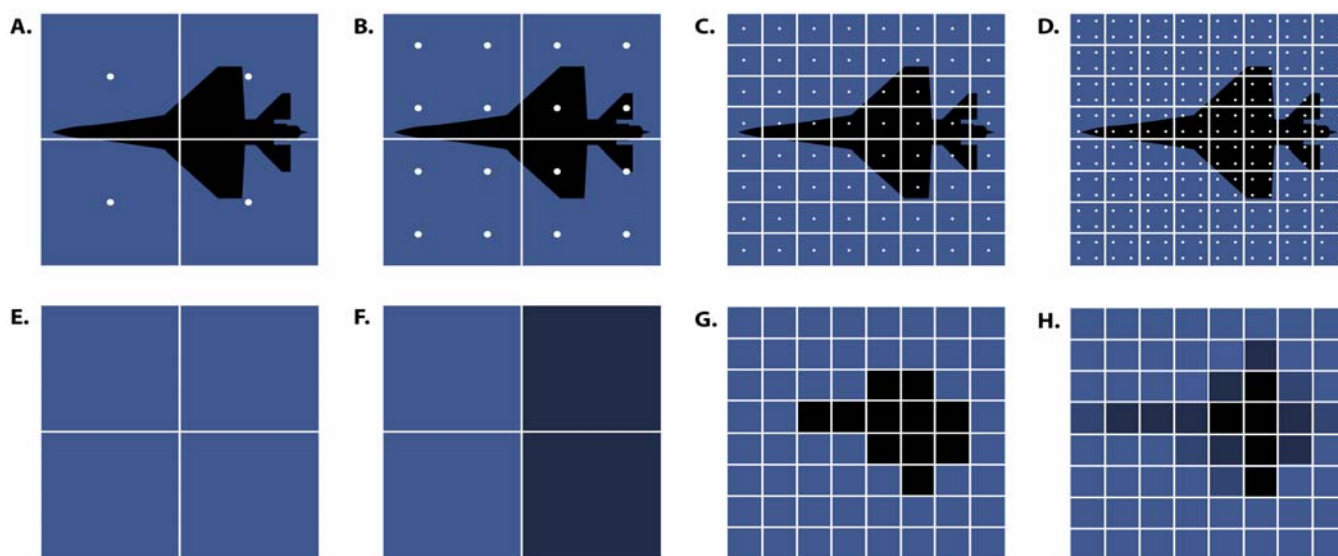

Figure 1. Effects of pixel resolution and 4x antialiasing on the representation of an F-16 at a 90° bank angle. The top row illustrates the aircraft projection, internal to the computer, and the sampling points. The bottom row illustrates the digital values of the computer-generated images.

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14. ABSTRACT
We assessed effects of flight-simulator spatial resolution and antialiasing on aircraft-roll detection range. We found that detection range increased with resolution and antialiasing. The antialiasing effect was greater for the lower resolution. These effects held over three levels of aircraft-roll magnitude (task difficulty).

15. SUBJECT TERMS
Image generation; Aircraft roll detection; Detection range; Spatial resolution; Antialiasing; Task difficulty; Visual perception; Visual systems; Flight simulators

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2.   Methods
2.2   Observers, Apparatus, and Stimuli

Five men and seven women with normal or corrected-to-normal vision participated in this experiment. We used two personal computers, a host and an IG, both running Windows 2000. The IG was equipped with an NVIDIA GeForce4 graphics card set to 32-bit color, a pixel resolution of 1280 x 1024, and a 60-Hz update rate. The analog video signals were input to a Barco 909 CRT projector set to a refresh rate of 60-Hz. The images were rear projected onto a Proscreen 54.3 x 45.5 in screen with a 1.2 gain. The projected-image size was 51.2 × 41.3 in.

We used MetaVR's WorldPerfect™ to build a virtual world consisting of a blue (R, G, B values of 67, 90, 150) sky and a black, three-dimensional model of an F-16. The scenes were rendered with MetaVR's real-time visualization application, Virtual Reality Scene Generator (VRSG) ™. We used custom software to control the characteristics and timing of the motion sequences and to record observers' responses.

We varied the FOV specified in the IG and the viewing distance of the observer in order to create two levels of IG resolution (4 and 1 arcmin/pixel). We selected either 'none' or '4x' antialiasing on the graphics-card driver.

A trial consisted of two 3.0-sec presentations of the F-16. In one of the two presentations, the aircraft rolled; in the other, it did not. Each roll sequence consisted of four subintervals. During the first 0.5 sec, the aircraft held its initial bank angle; during the next 1.0 sec, it rolled at a constant speed; during the next 1.0 sec, it rolled back to its initial bank angle, which it maintained during the final 0.5 sec. The F-16 rolled from either (a) a bank angle of 0° to the "designated" bank angle (22.5, 45, or 90º) and back to 0° or (b) the designated bank angle to 0° and back to the designated bank angle. The bank angle in the sequence without roll matched the initial bank angle in the sequence with roll.

The aircraft model was always approximately centered within the image, with its long axis perpendicular to the viewing direction. However, in order to simulate the slight variations in relative aircraft position that occur during real formation flight and to minimize systematic sampling effects resulting from a particular alignment of the aircraft and the pixel mosaic, the model's position was varied slightly during each sequence. This variation was determined by the sum of horizontal and vertical sine waves.

2.3   Design and Procedure

We used a two-interval, forced choice, adaptive staircase procedure [4] to estimate the roll-detection-range threshold. The simulated distance for the first trial was 2000 m (1.08 nm). The distance on subsequent trials depended on the observer's response history, the rule for controlling change in simulated distance, and the step size. Both the step size and the rule were varied during the course of a staircase. The final step size was 0.05 $\log_{10}$ meters; the final rule converged on 0.794 correct.

Each observer was tested with all 24 combinations of two resolutions (1 and 4 arcmin/pixel), two antialiasing options (none and 4x), three roll magnitudes (22.5°, 45° and 90°), and two roll directions (0° to designated bank angle or designated bank angle to 0°). Resolution, antialiasing, and roll-magnitude presentation orders were counterbalanced across observers. Trials for the two roll directions were interleaved. On each trial, observers indicated, by a button press on a joystick, in which presentation the aircraft was rolling.

3.   Results and Discussion

We subjected the threshold distance measures ($\log_{10}$ meters) to a repeated measures analysis of variance. As shown in Figure 2, detection threshold increased significantly with resolution,
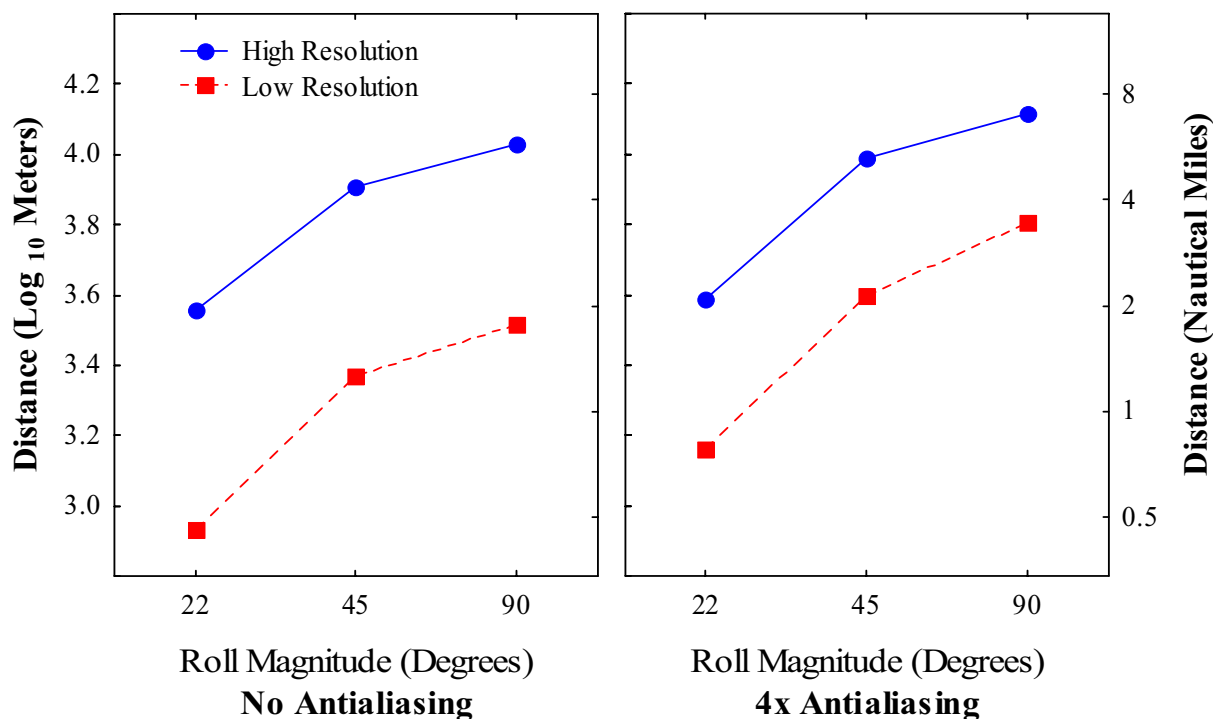

Figure 2. Mean detection range as a function of roll magnitude for each combination of resolution and antialiasing. Distance is shown in log10 meters on the left axis and in nautical miles on the right axis.
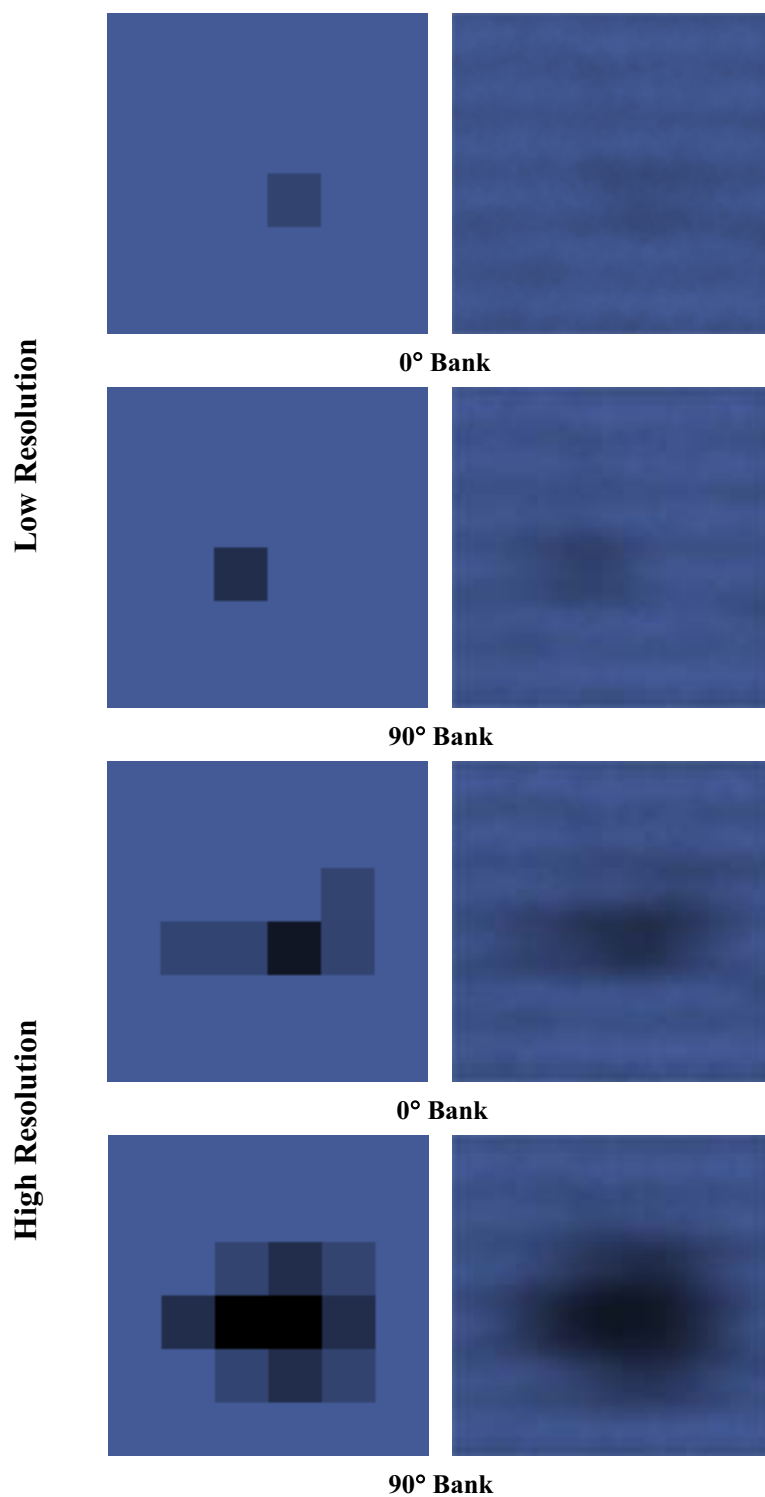
Figure 3. Square pixel (left) and display (right) representations of the F-16 at the median threshold ranges (4.3 nm with 4 arcmin resolution and 7.0 nm with 1 arcmin resolution) for the 4x antialiasing, 90° roll, 0°-start conditions. Note that relative angular size is not portrayed here.

$F(1,11) = 597.81$, $p < .000001$, antialiasing, $F(1,11) = 100.32$, $p < .000001$, and roll magnitude, $F(2,22) = 582.83$, $p < .000001$. A significant Resolution x Antialiasing interaction, $F(1,11) = 21.208$, $p < .001$, reflected a larger effect of antialiasing for the lower of the two resolutions. A significant Resolution x Roll Magnitude interaction, $F(2,22) = 4.54$, $p < .05$, reflected a decrease in the size of the resolution effect with an increase in roll magnitude. In addition, both roll magnitude and resolution interacted significantly with roll direction, but the effects were small and not readily interpretable.

The length of an object projection is inversely proportional to the viewing distance. The higher-resolution pixel was 1/4 the width of the lower-resolution pixel. Thus, if observers used the same pixel information to detect a given roll magnitude, regardless of the angular size of the pixel, then the detection ranges for the two resolutions would have differed by a factor of 4.0. Without antialiasing, the average detection range for the 22.5º roll was 4.2 times as large for the 1-arcmin resolution as for the 4-arcmin resolution. This finding indicates that the representations of the aircraft at the lower resolution actually consisted of *more* pixels than the representations at the higher resolution. In contrast, for the largest roll magnitude with 4x antialiasing, the ratio was reduced to 2.0, indicating that the lower-resolution depictions of the aircraft would have had approximately half as many pixels as the higher-resolution depictions and that resolution affected the image changes (relative size, contrast, or shape) observers used to detect roll.

The particular characteristics of our display system may have contributed to the resolution and antialiasing effects. In contrast to the pixel representations in Figure 1, CRT-based display pixels are not square, and pixel luminance is not a linear function of voltage [6]. Moreover, with our display, the raster lines did not overlap enough to create a uniform background, resulting in a raster-line dependent grating of 1 cycle per pixel—fundamental spatial frequencies of 60 cycles/deg and 15 cycles/deg for the 1- and 4-arcmin resolutions, respectively [5]. Given the resolution of the human visual system, this "noise pattern" was much more likely to have been visible for the lower-of the two resolutions.

These display characteristics can be seen in Figure 3, which shows square pixel portrayals of sampled values (left column) and camera shots of display images (right column) of F-16 representations at the median threshold ranges for the 4x antialiasing, 90° roll, 0º start conditions. Figure 3 also illustrates resolution-dependent differences in the cues for roll detection. At the detection thresholds, the lower-resolution representations of the F-16 at bank angles of 0° and 90° sometimes differed only in contrast, whereas the higher-resolution representations typically differed in size, shape, and contrast. With a 4-arcmin pixel, then, observers may have been able to discriminate change in contrast of a single pixel. With a 1-arcmin pixel, a mere change in contrast of 1 or 2 pixels was apparently not a sufficient cue.

4. Conclusions
We expect that the primary results of this experiment, that is, the positive effects of resolution and antialiasing as well as the larger effect of antialiasing for the lower resolution, would hold over a wide range of change-detection, discrimination, and identification tasks and for most database variations. However, the interactions (or lack thereof) of these variables with task difficulty may very well be task, database, and display specific.

With current technology, pixels typically subtend 3-4 arcmin. In next-generation technology (under development at AFRL, Mesa), each pixel will subtend 1 arcmin. Our findings suggest that new ultra-high resolution visual systems will significantly improve simulator training capabilities for tasks requiring detection of small changes in the relative orientation of distant objects. Antialiasing should further enhance training effectiveness. With an ultra-high resolution system, however, the positive effects of antialiasing may not be sufficient to justify the allocation of processing resources.

5. Acknowledgements

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